Kilo-Hertz QPO and X-ray Bursts in 4U 1608-52 in Low Intensity State

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Abstract. We present the results from RXTE/PCA observations of 4U 1608-52 in its island state on March 15, 18 and 22 of 1996. Three type I X-ray bursts were detected in one RXTE orbit on March 22. We observed QPO features peaking at 567-800 Hz on March 15 and 22, with source fractional rms amplitude of 13%-17% and widths of 78-180 Hz in the power density spectra averaged over each spacecraft orbit. The rms amplitudes of these QPOs are positively correlated with the photon energy. The three X-ray bursts, with burst intervals of 16 and 8 minutes, have a duration of 16s. The blackbody emission region of the smallest X-ray burst among the three suggest it was a local nuclear burning. We also discuss a type I X-ray burst candidate in the observation.

INTRODUCTION

4U 1608-52 is a transient X-ray burster with recurrence intervals from 80 days to about 2 years [1] [2]. It was classified as an atoll source based on the correlated X-ray spectral variability and High-Frequency- Noise (HFN) [3] [4]. 4U 1608-52 is known to show spectral and timing characteristics similar to those in blackhole candidates (BHCs) in the low state [5]. When in a low luminosity state ($L_x \leq 10^{37}$erg/s), its energy spectrum above 2 keV is usually dominated by a power-law component [4] [6] [7], which is gradually cut off above $\sim 60 - 70$ keV [8].

An outburst was observed from 4U 1608-52 with RXTE in early 1996 [9]. A few RXTE/PCA pointings on March 3, 6, 9 and 12 show kilo-hertz QPO at 690-890 Hz [10]. Here we present our analysis results obtained from RXTE/PCA observations on March 15, 18 and 22 with source luminosity $\sim 10^{36}$ erg/s.

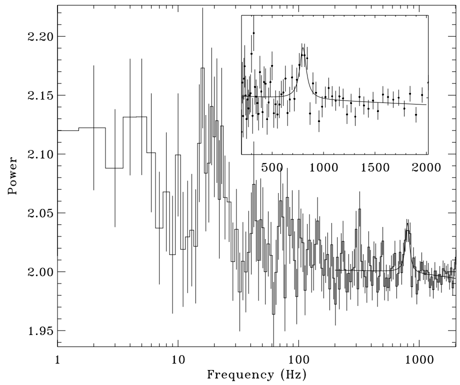

FIGURE 1. The QPO peak at 800 Hz in the first orbit on March 15. The PDS is complex and a broad peak at 20 Hz is also visible.

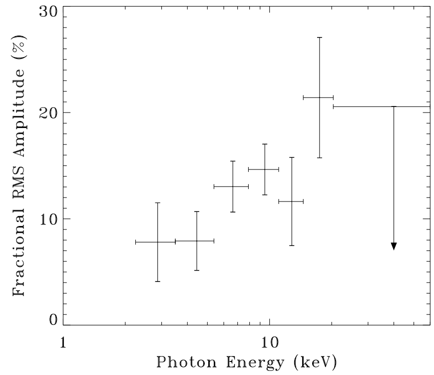

FIGURE 2. Average fractional *rms* amplitude of QPO as a function of photon energy. We average the results obtained from *Event Mode* data analysis of the 6 orbits.

OBSERVATIONS AND DATA ANALYSIS

The X-ray monitoring with RXTE/ASM shows that our observations on March 15, 18 and 22 were taken near the end of the outburst when source fluxes were below 50 mCrab. The persistent X-ray flux (2-20 keV) was $(4.6-11)\times 10^{-10}$erg/s/cm^2. The count rate ranged between 190-450 cps (1-60 keV) with source intensity below previous RXTE observations [10]. Three X-ray bursts were observed in one orbit on March 22.

Power Density Spectra (PDS)

By analyzing the *Event Mode* data with background subtraction, we have found that the Power Density Spectra (PDSs) were dominated by HFN with rms 10%-14% in our observations. We detect kilo-hertz QPO features at 567-800 Hz in 6 orbits , with source fractional rms amplitude of 13%-17% and widths of 78-180 Hz. As an example, Fig. 1 is the PDS obtained from the 1-30 keV *Event Mode* data averaged over the first orbit on March 15. We also investigate the energy dependence of the QPO features. A positive correlation between the average QPO rms amplitude and the photon energy is observed, as shown in Fig. 2. No kilo-hertz pulsations have been detected at 99% confidence level in the X-ray bursts in our preliminary searching. The details of the timing analysis will be reported elsewhere [11].

X-ray Bursts and Burst-like Variations

Three X-ray bursts were observed in the second orbit on March 22, 1996. They all have profiles consistent with a fast rise and exponential decay, and show blackbody-type energy spectra, indicating that they are type I X-ray bursts. Fig. 3 is the

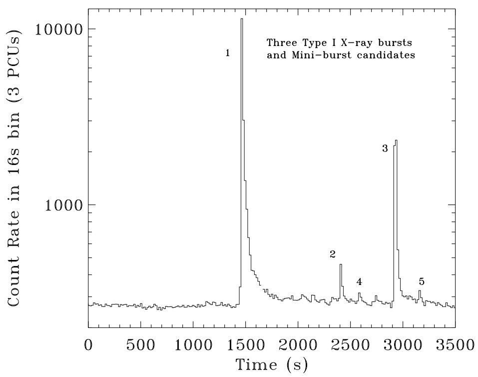

FIGURE 3. Three type I X-ray bursts (marked as 1-3) and mini-burst candidates (marked as 4-5). The time resolution is 16s and the count rates were obtained from 3 PCUs.

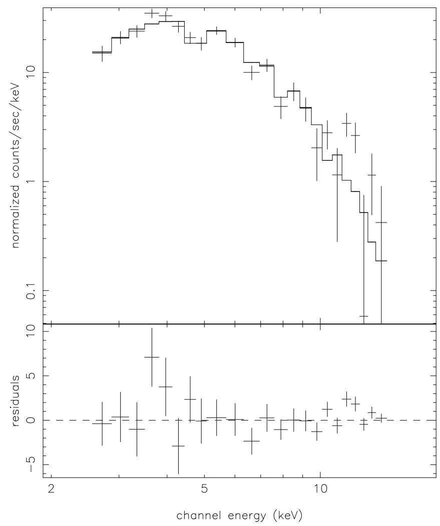

FIGURE 4. Energy spectrum of burst 2 with $kT_{BB} = 1.2$ keV and $\chi^2/21(dof) = 1.49$.

light curve with these bursts. The lightcurve is obtained from 3 PCUs and with 16 s resolution. The properties of these bursts are listed in Table 1. The average BB radii were obtained from spectral fitting to a BB model with $N_H = 1.5 \times 10^{22} cm^{-2}$.

The burst durations indicate that they belong to the "slow" class of bursts usually observed in 4U 1608-52 in its low state [12]. The intervals between the bursts were about 16 min and 8.5 min, among the shortest now known [1]. The ratio between the average persistent flux and the average burst flux of burst 3, regarding the relative time interval of 24 minutes between burst 1 and 3, was smaller than 6. In Fig. 4, we show the average energy spectrum of the burst 2 with the best fit BB

TABLE 1. Properties of Type I X-ray Bursts

Burst No.	Peak Count Rate (cps)[a]	Duration (s)[b]	BB Radius (km)[c]
1	16500	16.7 ± 0.1	~ 13
2	240	15.4 ± 1.0	~ 4
3	4150	16.7 ± 0.3	~ 18

[a] from 3 PCUs of RXTE/PCA
[b] defined as the ratio between the integrated burst counts and the burst peak count rate in PCA band
[c] from results of spectral fitting to a blackbody(BB) model with a correction assuming that the ratio between the color temperature and the effective temperature is 1.5

model with $N_H = 1.5 \times 10^{22} cm^{-2}$. The burst BB temperature was 1.2 ± 0.3 keV. The derived BB emission radius is smaller than the radii obtained for burst 1 and 3 (Table 1.).

Marked as 4 and 5 in Fig. 3 were burst-like intensity variations which were more than 4σ above the persistent intensity level in the light curve with the 10 s resolution during the entire observations. The second one was stronger. Its peak count rate in 3 PCUs was 90 ± 18 cps. Its profile can be fitted to a model with a linear rise and an exponential decay (see Fig.5). The derived rise time (from 10% to 90% of peak flux) and decay time (e-folding time) are 7.6 ± 1.3 s and 12.9 ± 2.5 s respectively. For the burst 2, the rise time and decay time are 8.2 ± 1.2 s and 13.1 ± 1.5 s. So they have similar profiles. In addition, the spectrum of this burst-like variation is consistent with the BB model, but a power law model can not be excluded. Fitting its spectra to a BB model yield a blackbody temperature of 1.2 ± 0.1 keV (Fig.6). Its corrected radius of BB emission region is 2.2 km. The hardness ratio (5.4-20.4 keV/2.2-5.4 keV) during the decay was also similar to that in burst 2.

DISCUSSION AND CONCLUSION

Strong HFN components in PDSs and low X-ray luminosity (2-20 keV) of $(0.7 - 1.7) \times 10^{36}$erg/s assuming a distance of 3.6 kpc suggest 4U 1608-52 was

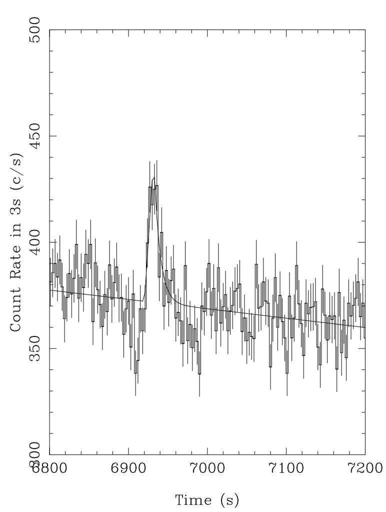

FIGURE 5. Time profile of one of the burst candidates (5). A model composed of a linear rise and an exponential decay was fit to the data.

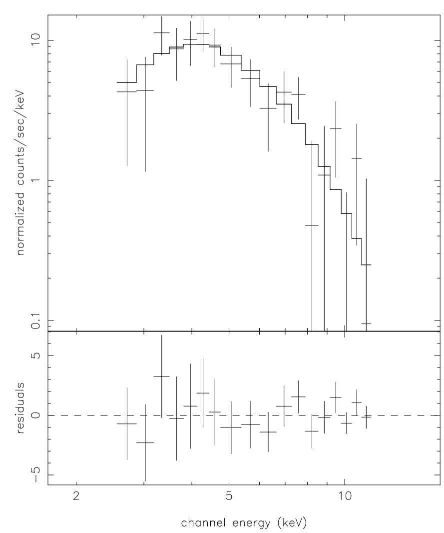

FIGURE 6. The Energy spectrum of the burst candidate (5) with $kT_{BB} = 1.2$ keV and $\chi^2/16(dof) = 0.51$.

in its island state [3]. The QPO features in our observations show a similar relation between QPO rms amplitude and photon energy to those observed in a higher intensity state [10]. The burst 3 cannot be explained as being produced by replenishing sufficient fuel through accretion within the short interval between burst 3 and burst 1. This suggest that a portion of the nuclear fuel had survived the previous bursts [1]. The burst 2 had a BB emitting radius smaller than those of the two stronger bursts and the size of the canonical neutron star radius. One burst-like intensity variation, which could not be observed with EXOSAT Medium Energy (ME) Experiment (estimated EXOSAT ME peak count rate (1-20 keV) is 12.4 c/s), also shows signatures of a type I X-ray burst with an even smaller BB emitting radius. This strongly supports the local nuclear burning interpretation. Our results suggest that these small bursts or variations, only observed associated with the strong bursts in our observations, may be attributed to the mixing mechanism during the post burst phase of the strong bursts [13].

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